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Widmann

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(54) PARALLEL PARKING ASSISTANT SYSTEM AND METHOD THEREOF

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G06F 19/00 (2006.01)

(52) **U.S. Cl.**
USPC **701/42**; 701/41; 701/44; 180/204

(58) **Field of Classification Search**
USPC 701/36, 23, 41, 42, 96, 44; 180/204
See application file for complete search history.

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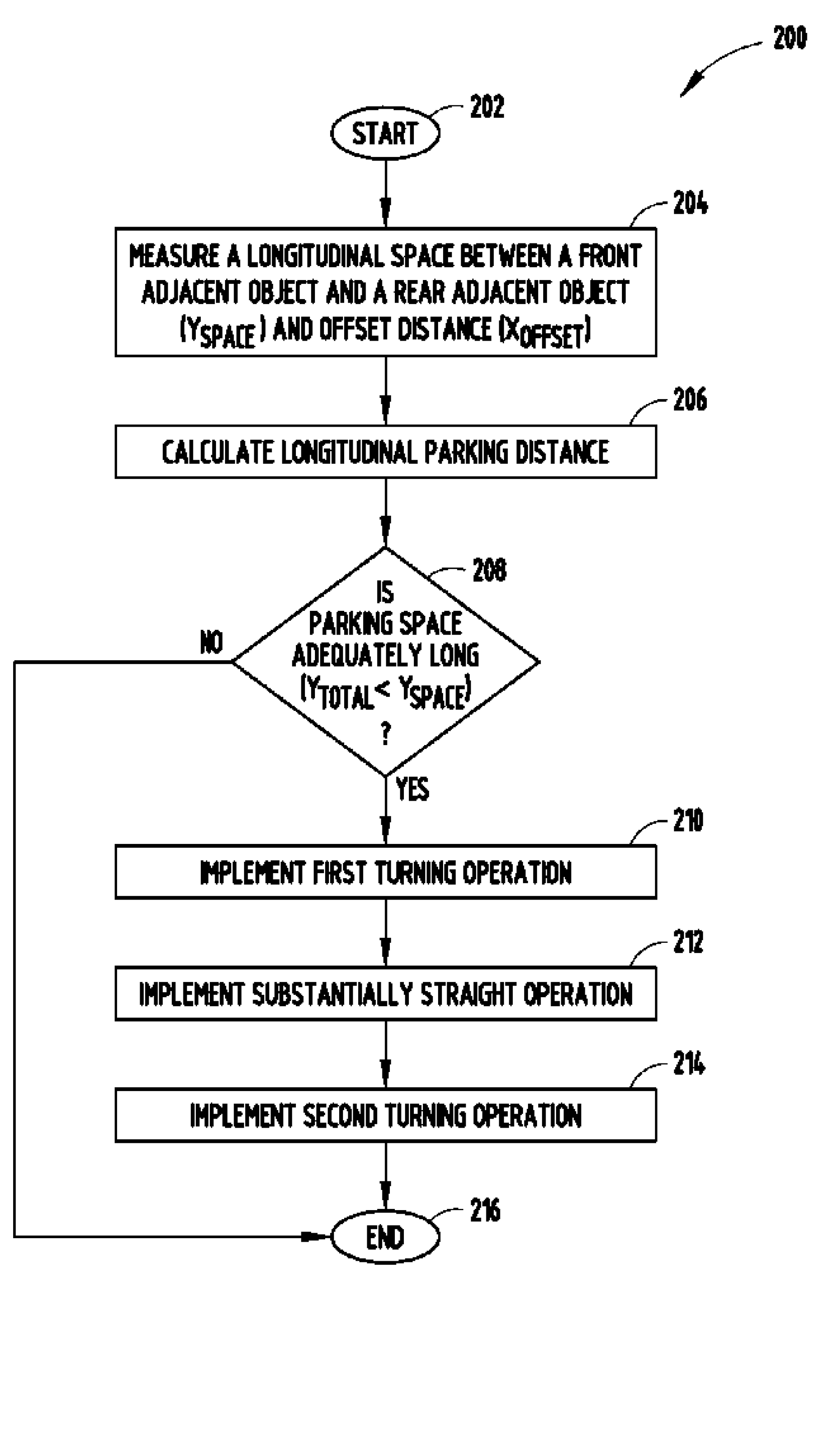
(57) **ABSTRACT**

A parallel parking assistant system integrated with a vehicle and method thereof are provided, the parking assistant system including a first sensor configured to determine a first distance, a second sensor configured to determine a second distance, and a controller configured to provide commands as a function of the first and second determined distances. The commands include a first command configured to command a steering system to be in a clockwise position while the vehicle is moving in a reverse direction for a first reversing distance, a second command configured to command the steering system to be in a substantially straight position while the vehicle is moving in a reverse direction for a second reversing distance, and a third command configured to command the steering system to be in a counter-clockwise position while the vehicle is a moving in a reverse direction for a third reversing distance.

7 Claims, 7 Drawing Sheets



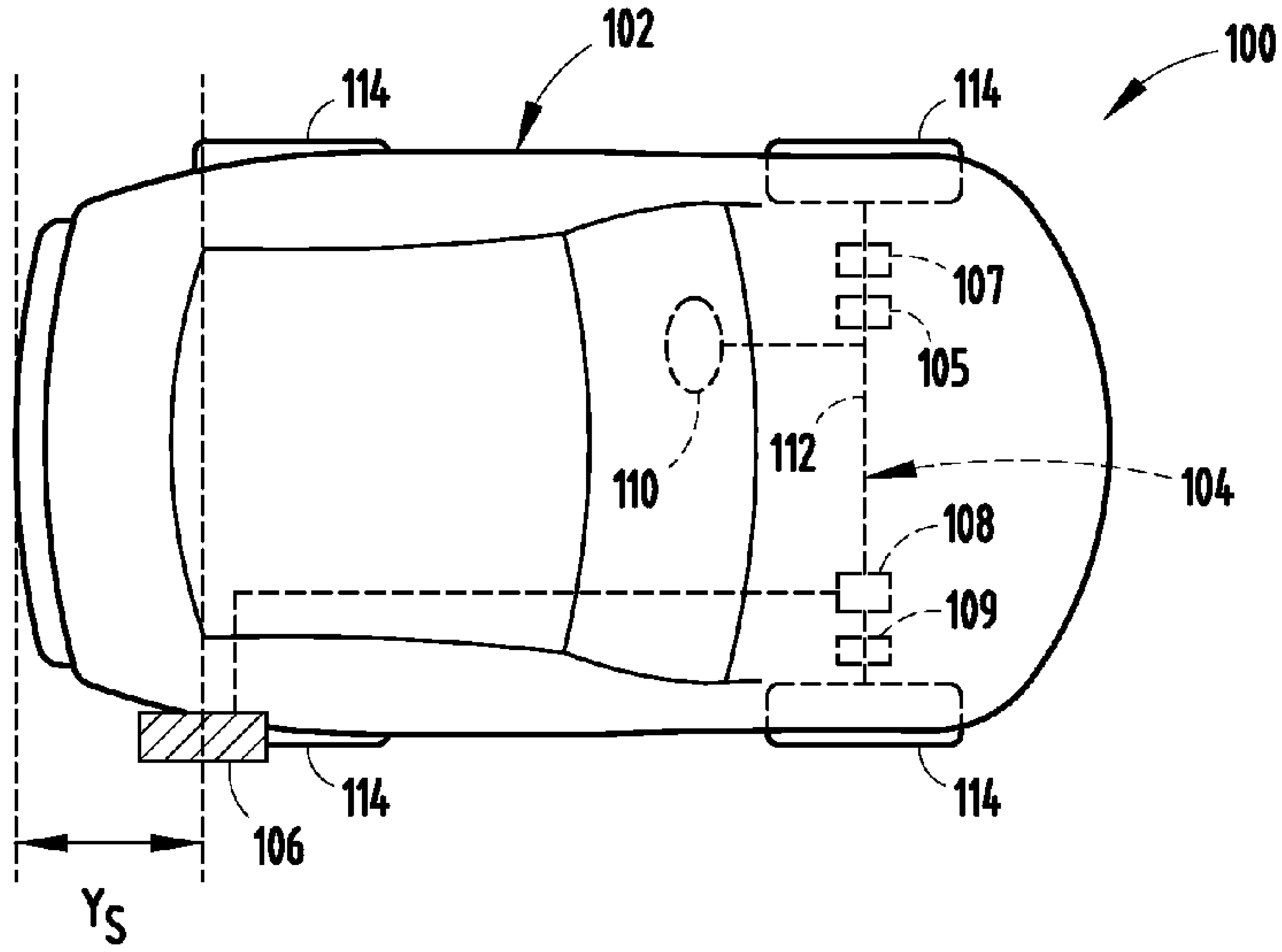


FIG. 1

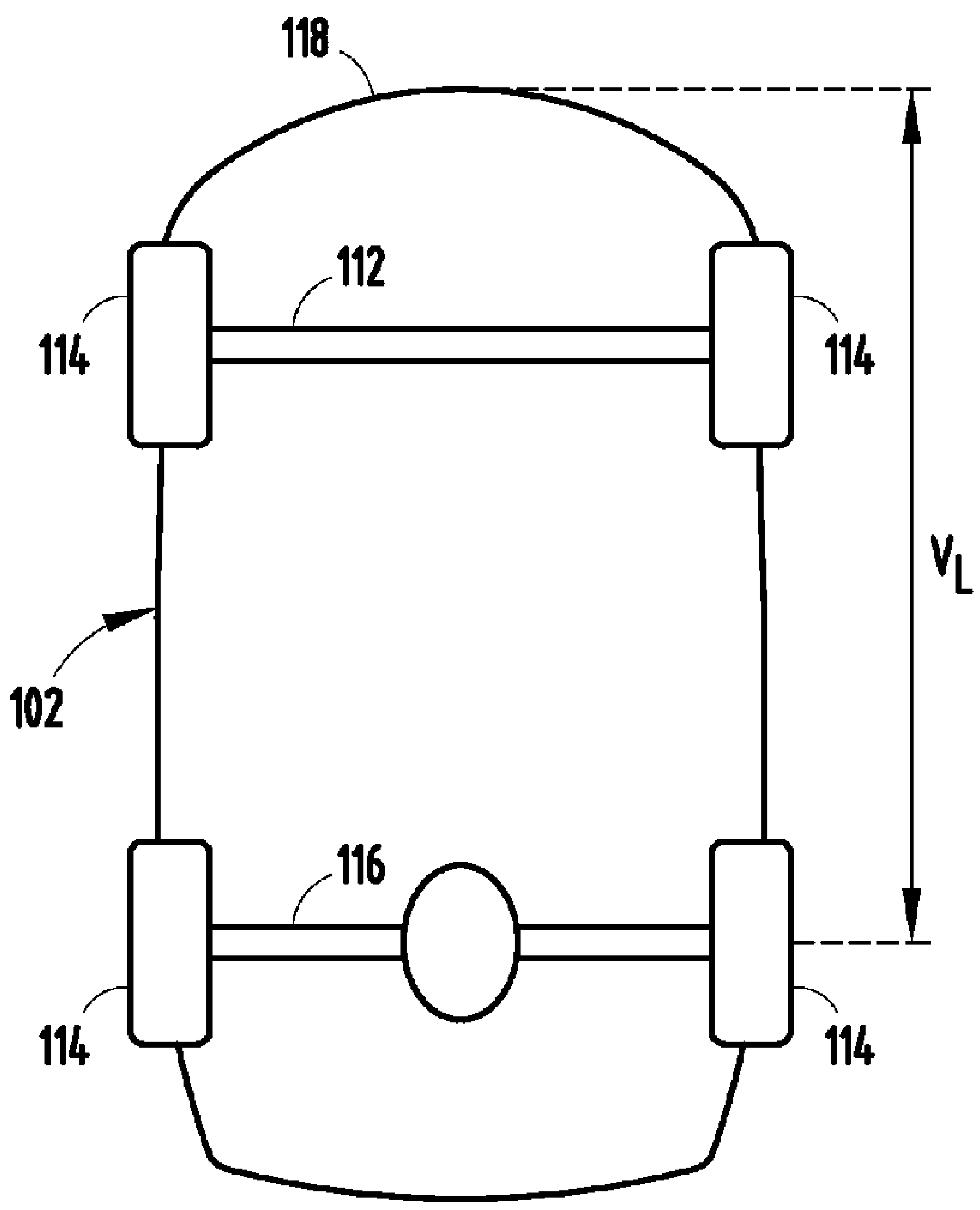


FIG. 2A

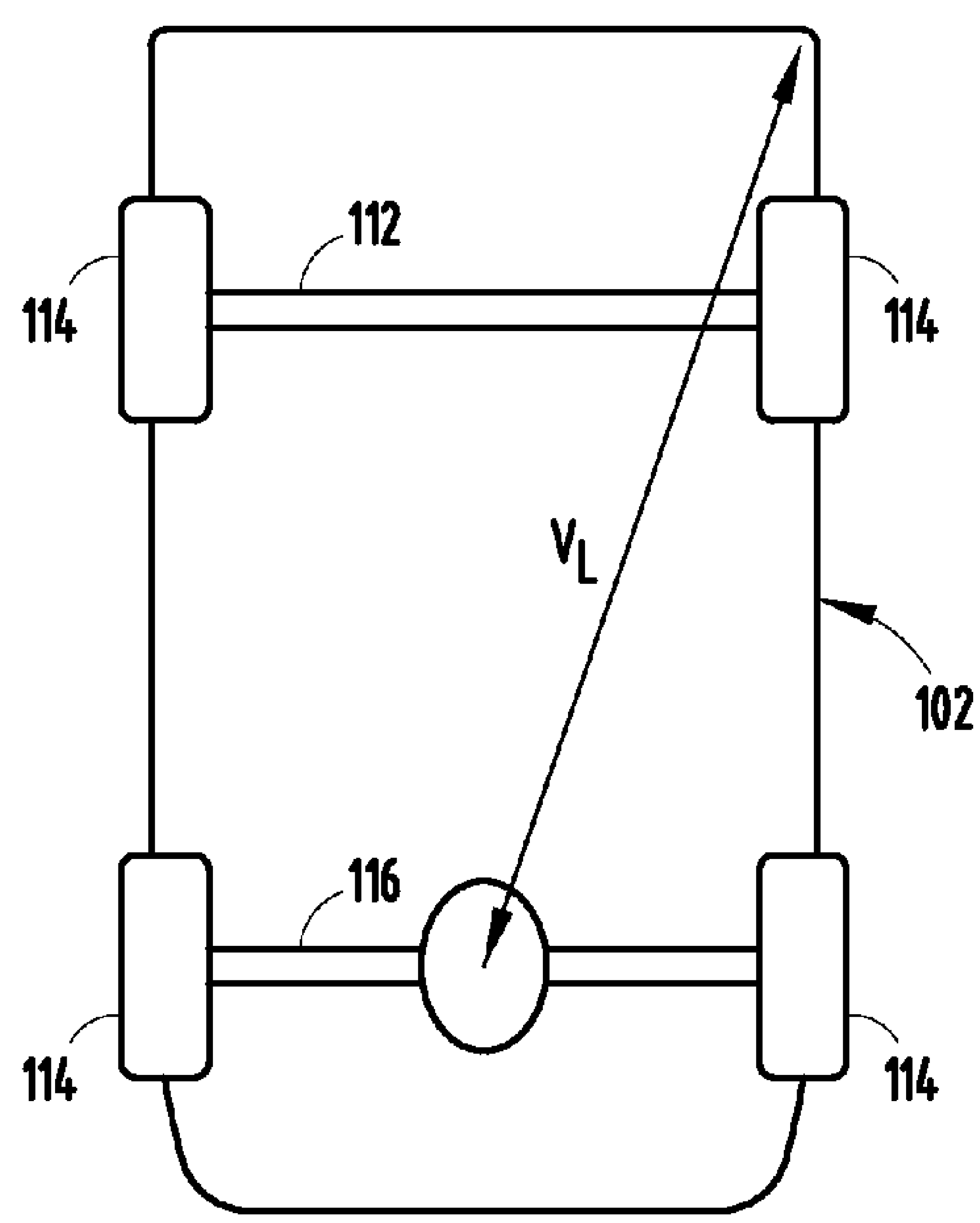


FIG. 2B

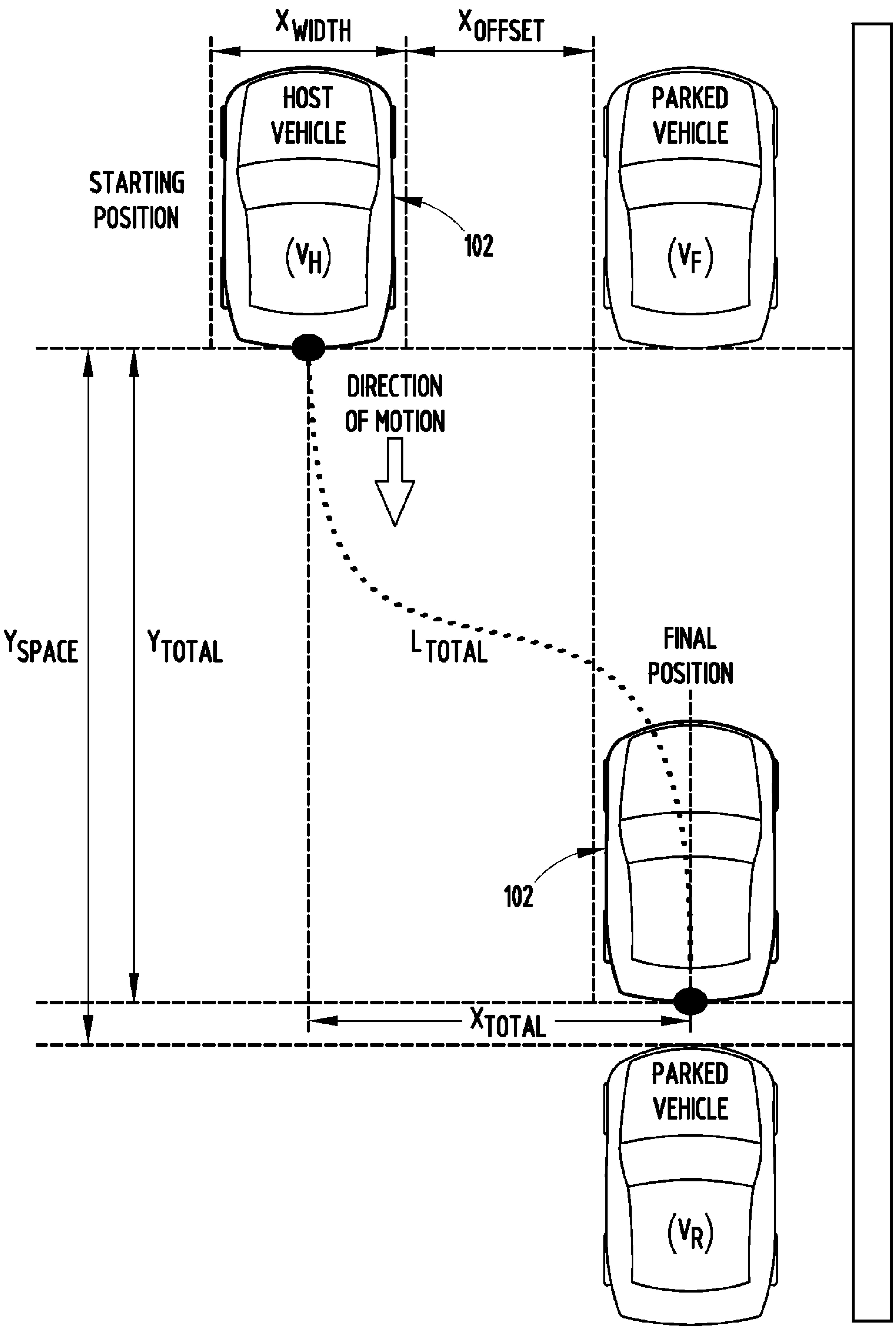

X WIDTH
X OFFSET
HOST VEHICLE
PARKED VEHICLE
STARTING POSITION
102
(V H)
(V F)
DIRECTION OF MOTION
Y SPACE
Y TOTAL
L TOTAL
FINAL POSITION
102
X TOTAL
PARKED VEHICLE
(V R)

FIG. 3

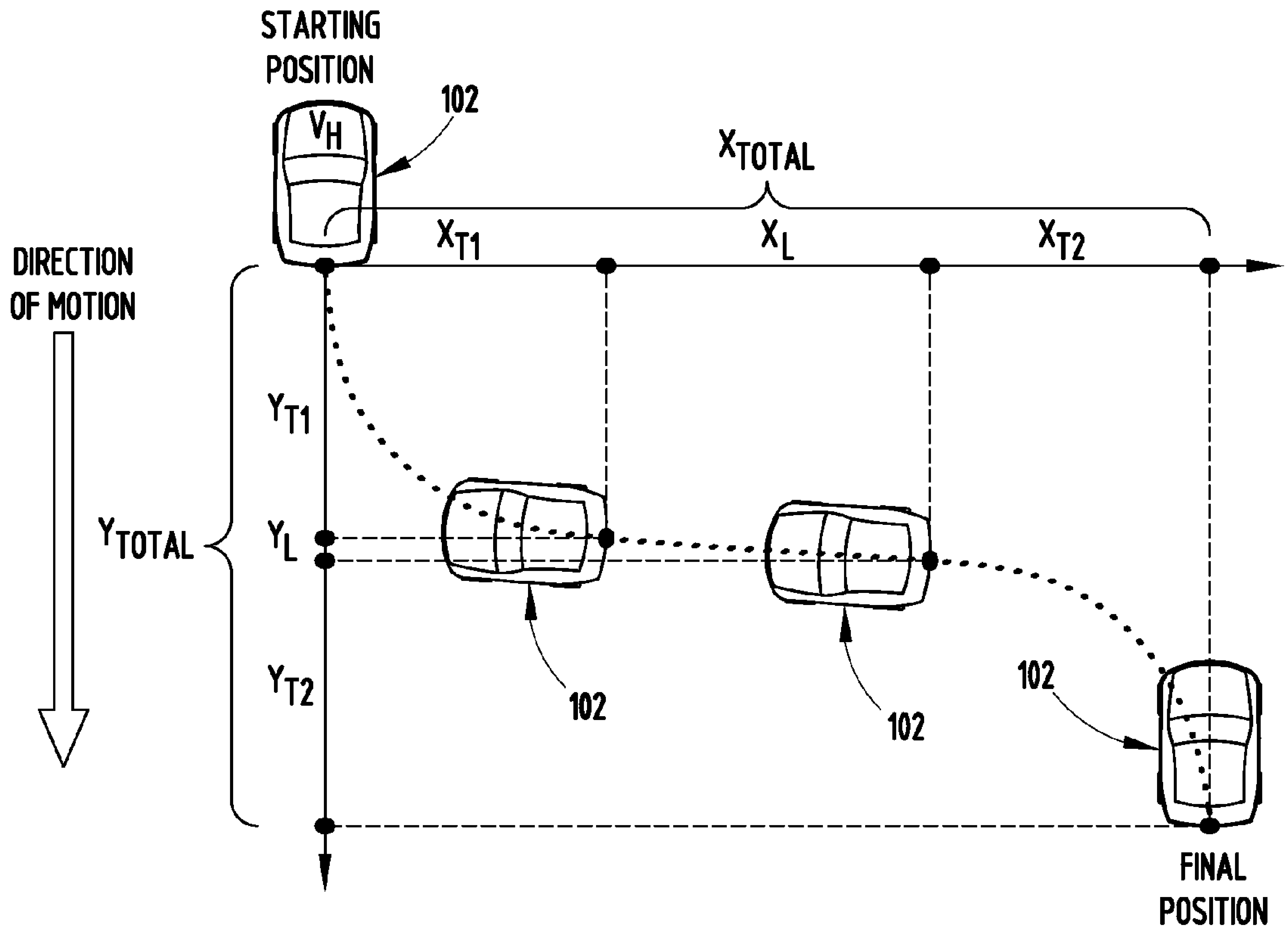
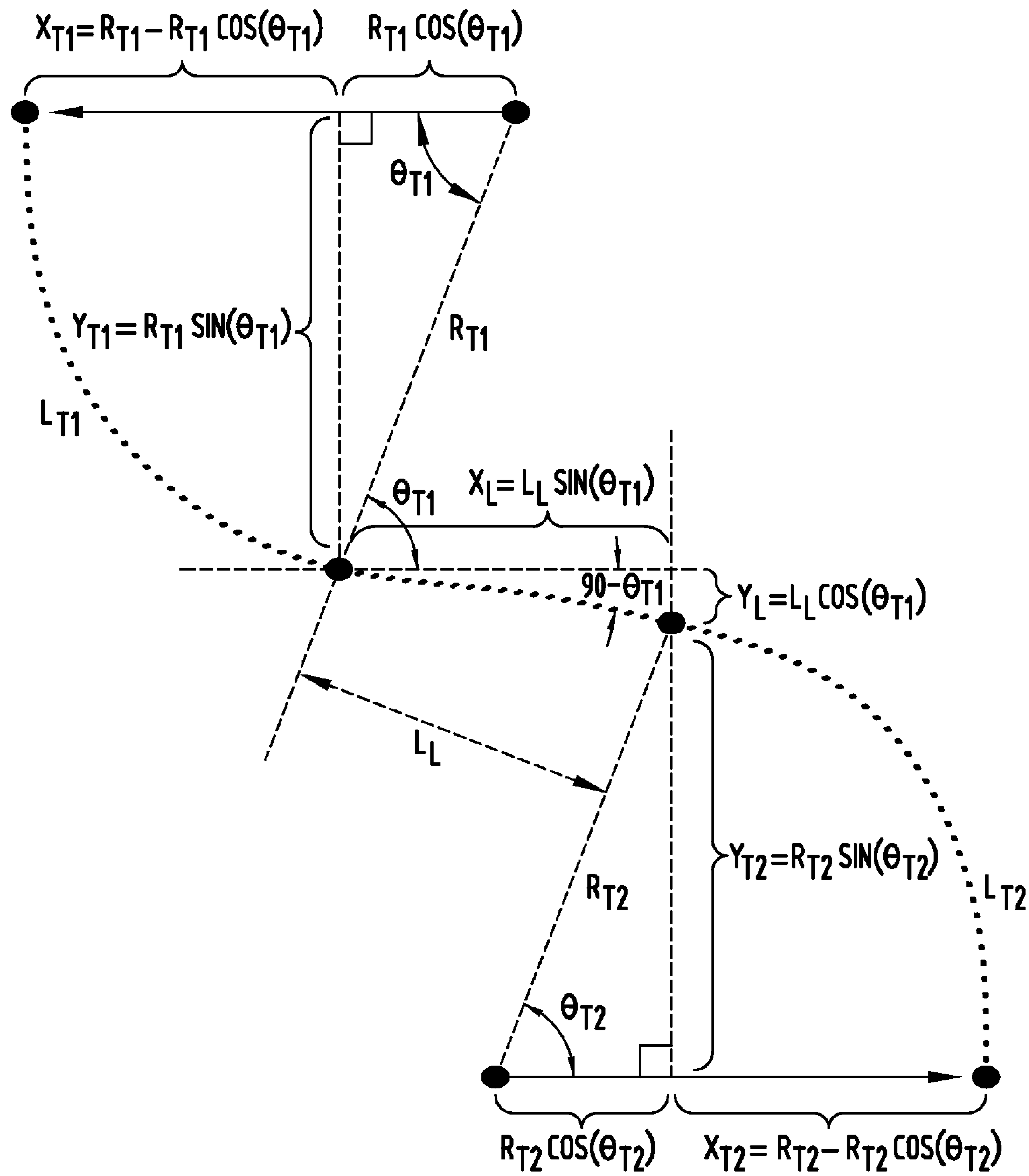

STARTING POSITION
102
V_H
X_TOTAL
X_T1
X_L
X_T2
DIRECTION OF MOTION
Y_T1
Y_TOTAL
Y_L
Y_T2
102
102
102
FINAL POSITION

FIG. 4



$X_{T1}=R_{T1}-R_{T1}\cos(\theta_{T1})$
$R_{T1}\cos(\theta_{T1})$
θ_{T1}
$Y_{T1}=R_{T1}\sin(\theta_{T1})$
R_{T1}
L_{T1}
θ_{T1}
$X_L=L_L\sin(\theta_{T1})$
$90-\theta_{T1}$
$Y_L=L_L\cos(\theta_{T1})$
L_L
$Y_{T2}=R_{T2}\sin(\theta_{T2})$
R_{T2}
L_{T2}
θ_{T2}
$R_{T2}\cos(\theta_{T2})$
$X_{T2}=R_{T2}-R_{T2}\cos(\theta_{T2})$

FIG. 5

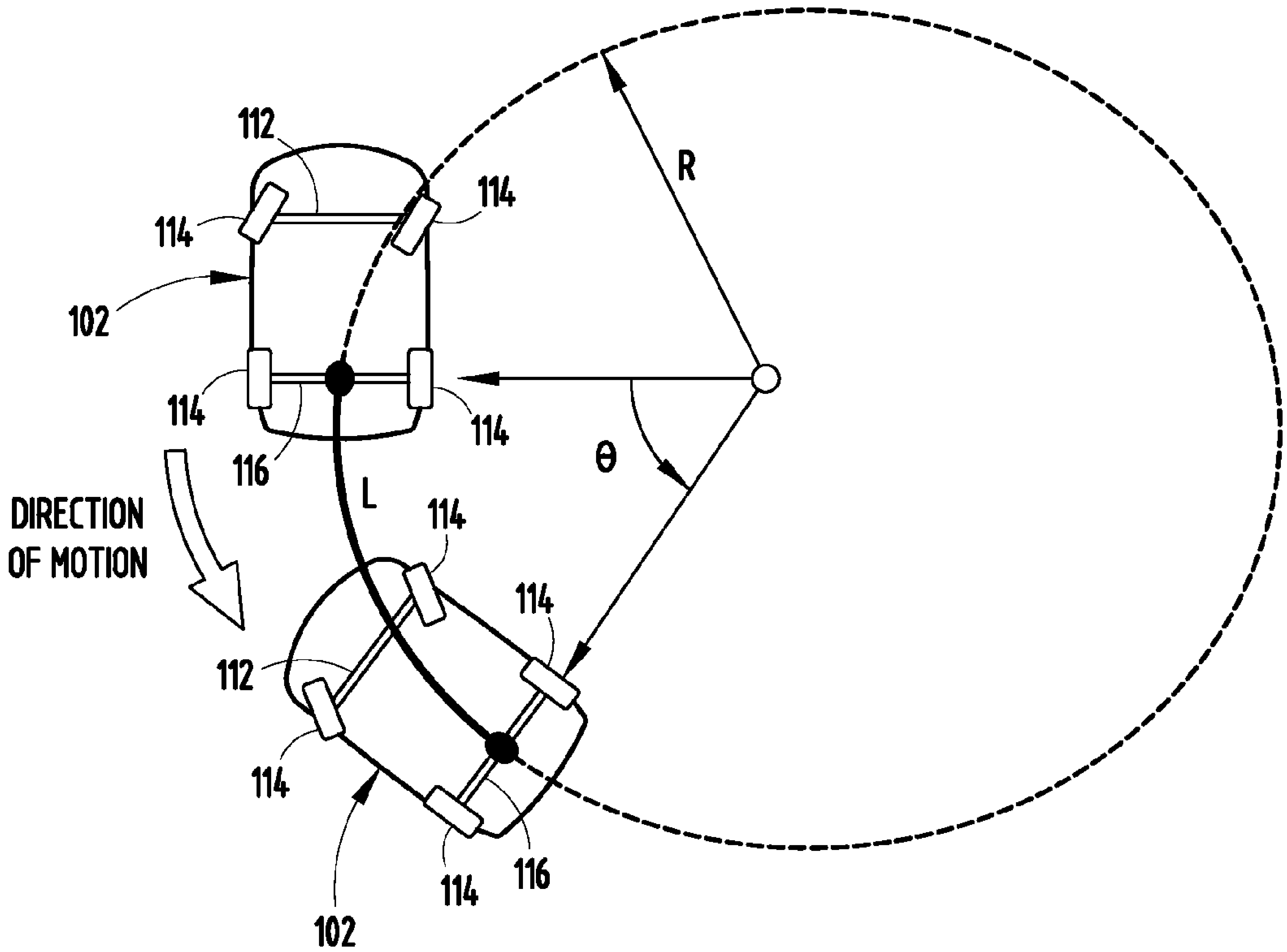

112
114
114
102
114
114
116
R
θ
L
DIRECTION
OF MOTION
114
114
112
114
114
116
102

FIG. 6

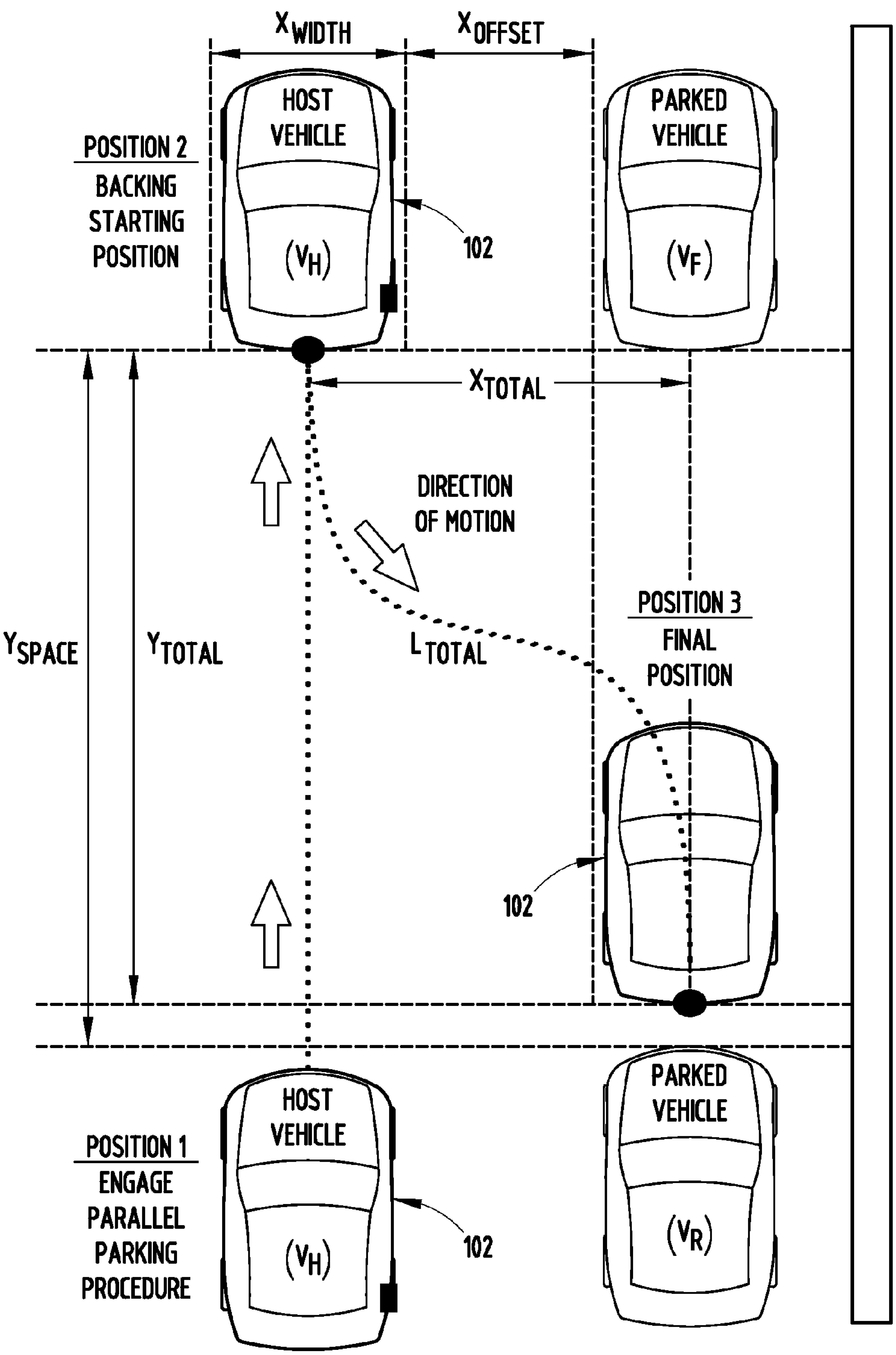

X WIDTH
X OFFSET
HOST VEHICLE
PARKED VEHICLE
POSITION 2
BACKING STARTING POSITION
(VH)
(VF)
102
X TOTAL
DIRECTION OF MOTION
POSITION 3
FINAL POSITION
Y SPACE
Y TOTAL
L TOTAL
102
HOST VEHICLE
PARKED VEHICLE
POSITION 1
ENGAGE PARALLEL PARKING PROCEDURE
(VH)
(VR)
102

FIG. 7

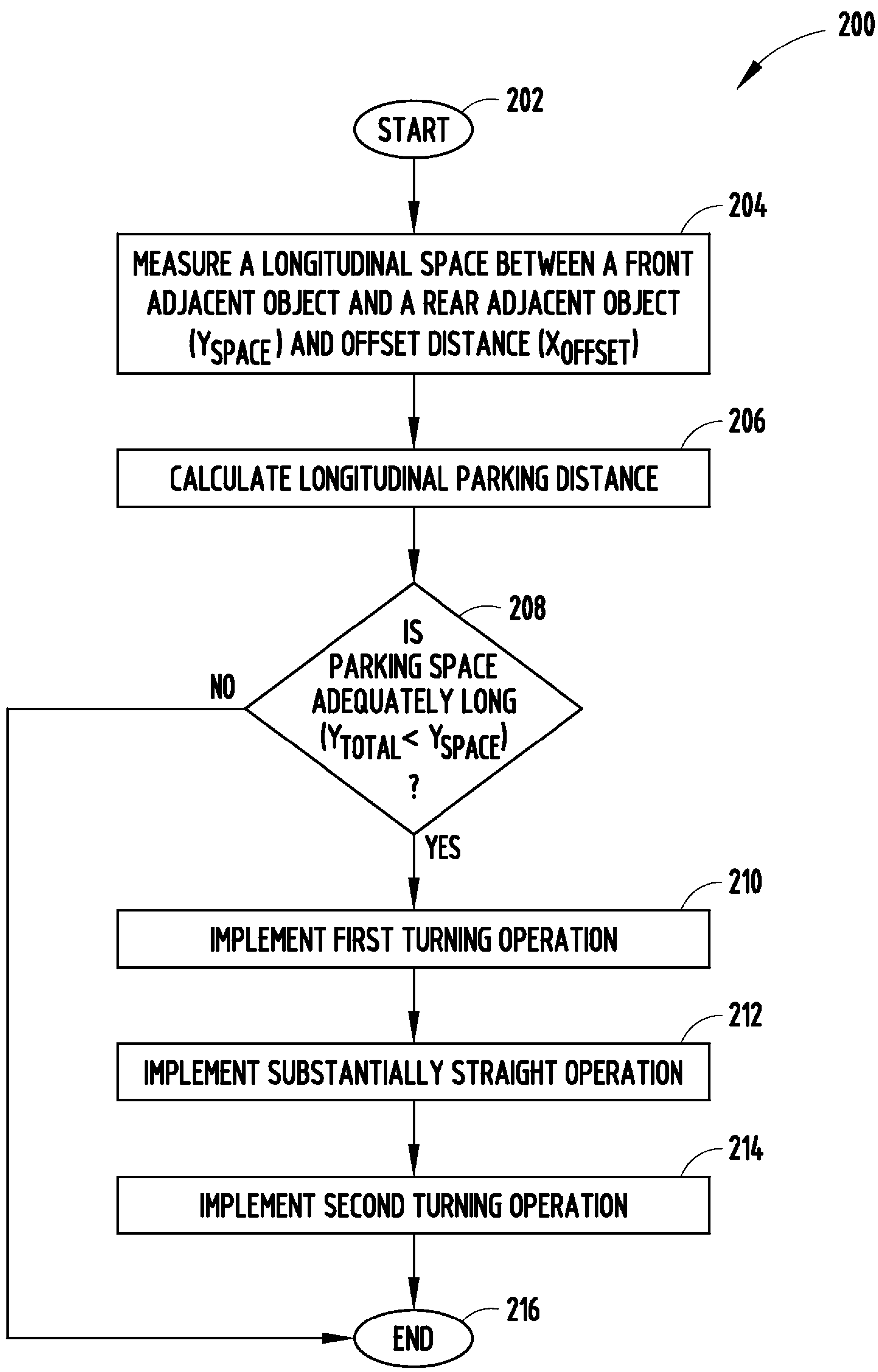

200
START
202
MEASURE A LONGITUDINAL SPACE BETWEEN A FRONT ADJACENT OBJECT AND A REAR ADJACENT OBJECT (Y_{SPACE}) AND OFFSET DISTANCE (X_{OFFSET})
204
CALCULATE LONGITUDINAL PARKING DISTANCE
206
IS PARKING SPACE ADEQUATELY LONG ($Y_{TOTAL} < Y_{SPACE}$) ?
208
NO
YES
IMPLEMENT FIRST TURNING OPERATION
210
IMPLEMENT SUBSTANTIALLY STRAIGHT OPERATION
212
IMPLEMENT SECOND TURNING OPERATION
214
END
216

FIG. 8

PARALLEL PARKING ASSISTANT SYSTEM AND METHOD THEREOF

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional application of U.S. Ser. No. 12/758,218, filed Apr. 12, 2012, entitled "PARALLEL PARKING ASSISTANT SYSTEM AND METHOD THEREOF"

FIELD OF THE INVENTION

The present invention generally relates to a parking assistant system and method thereof, and more particularly, a parallel parking assistant system integrated with a vehicle and a method thereof.

BACKGROUND OF THE INVENTION

Generally, autonomous parallel parking systems require the use of multiple distance sensors that are strategically located at various locations around a host vehicle body structure, such as a front-side fascia, a rear-side fascia, a front bumper, and a rear bumper. These sensors can collectively measure various displacements between the host vehicle and adjacent parked vehicles. The controller can use these various displacement measurements to implement algorithms to adjust a steer angle of the host vehicle to allow the host vehicle to back into the parking space and avoid impacting the adjacent parked vehicles.

These parallel-parking systems can be expensive due to the cost of the multiple sensors and the controller that processes the algorithms. Typically, the parallel-parking system implementation can require the additional cost of controllable steering (e.g., electric power steering), controllable brakes, and controllable throttles.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, a parallel parking assistant system integrated with a vehicle that includes a steering system, a brake system, and a throttle system is provided. The parking assistant system includes a first sensor configured to determine a first distance to an object adjacent to a side of the vehicle, a second sensor configured to determine a second distance between a forward positioned object and a rear positioned object that define a parking space, and a controller in communication with the first and second sensors, wherein the controller is configured to provide commands to control the steering system, the brake system, and the throttle system of the vehicle as a function of the first and second determined distances. The commands include a first command configured to command the steering system to be in a clockwise position while the vehicle is moving in a reverse direction for a first reversing distance, a second command configured to command the steering system to be in a substantially straight position while the vehicle is moving in a reverse direction for a second reversing distance, wherein a distance traveled during the first and second reversing distances is a function of a length of the vehicle, and a third command configured to command the steering system to be in a counter-clockwise position while the vehicle is a moving in a reverse direction for a third reversing distance, wherein a distance traveled during the first, second, and third reversing distances is a function of the determined first and second distances, a longitudinal displacement of the vehicle during the first, second, and third commands, and a lateral displacement of the vehicle during the first, second, and third commands.

According to another aspect of the present invention, a method of parallel parking a vehicle including a steering system is provided. The method includes the steps of determining a first distance between a side of the vehicle and an object adjacent the side of the vehicle, determining a second distance between a forward positioned object and rear positioned object that define a parking space, rotating the steering system in a clockwise direction while the vehicle is moving in a reverse direction for a first reversing direction, rotating the steering system to a substantially straight position while the vehicle is moving in a reverse direction for a second reversing direction, wherein a distance traveled during the first and second reversing distances is a function of a length of the vehicle, and rotating the steering system to a counter-clockwise direction while the vehicle is moving in a reverse direction for a third reversing direction, wherein a distance traveled during the first, second, and third distances is a function of the determined distance, a longitudinal displacement of the vehicle during the rotating the steering system step, and a lateral displacement of the vehicle during the rotating the steering system step.

According to yet another aspect of the present invention, a method of parallel parking a host vehicle is provided that includes the steps of determining a lateral and longitudinal distance of a parking space, determining an offset distance between the host vehicle and an adjacent forward positioned object, implementing a first substantially maximum turning operation while displacing the vehicle a first reversing distance, implementing a substantially straight operation while displacing the vehicle a second reversing distance, and implementing a second substantially maximum turning operation while displacing the vehicle a third reversing distance, wherein the first substantially maximum turning operation and the second substantially maximum turning operation are different directions.

These and other features, advantages, and objects of the present invention will be further understood and appreciated by those skilled in the art by reference to the following specification, claims, and appended drawings

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. **1** is a schematic diagram of a parallel parking assistant system integrated with a vehicle, in accordance with one embodiment of the present invention;

FIG. **2**A is a schematic diagram of a vehicle illustrating an exemplary vehicle length V_L of a round-front vehicle, in accordance with one embodiment of the present invention;

FIG. **2**B is a schematic diagram of a vehicle illustrating an exemplary vehicle length V_L of a flat-front vehicle, in accordance with one embodiment of the present invention;

FIG. **3** is a schematic diagram illustrating an exemplary path of travel of a vehicle when parallel parking, in accordance with one embodiment of the present invention;

FIG. **4** is a schematic diagram illustrating an exemplary path of travel of a vehicle when parallel parking, in accordance with one embodiment of the present invention;

FIG. **5** is a schematic diagram illustrating an exemplary path of travel of a vehicle when parallel parking, in accordance with one embodiment of the present invention;

FIG. **6** is a schematic diagram illustrating an exemplary path of travel of a vehicle when a steering system of the vehicle is turned to a substantially locked position in a clockwise direction, in accordance with one embodiment of the present invention;

FIG. **7** is a schematic diagram illustrating an exemplary path of travel of a vehicle when parallel parking, in accordance with one embodiment of the present invention; and

FIG. **8** is a flowchart illustrating a method of parallel parking a vehicle, in accordance with one embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

In regards to FIG. **1**, a parallel parking assistant system is generally shown at reference identifier **100**. Typically, the parallel parking assistant system **100** is integrated with a vehicle, which is generally indicated at reference identifier **102** and/or V_H, and can include a steering system that is generally indicated at reference identifier **104**, a brake system **105**, and a throttle system **107**. The parallel parking assistant system **100** can further include a first sensor **106** that is configured to determine a first distance to an object adjacent to a side of the vehicle **102**, V_H (FIGS. **3-5** and **7**), and a second sensor **109** configured to determine a second distance between a forward positioned object and a rear positioned object that define a parking space. The parallel parking assistant system **100** can also include a controller **108** in communication with the first sensor **106** and the second sensor **109**, wherein the controller **108** is configured to provide commands to the steering system **104**, the brake system **105**, and the throttle system **107** of the vehicle **102**, V_H for steering the vehicle **102**, V_H as a function of the determined first and second distances.

The commands provided by the controller **108** can include a first command configured to command the steering system **104** to be in a clockwise position while the vehicle **102**, V_H is moving in a reverse direction for a first reversing distance. The commands provided by the controller **108** can further include a second command configured to command the steering system **104** to be in a substantially straight position while the vehicle **102**, V_H is moving in a reverse direction for a second reversing distance, wherein a distance traveled during the first and second reversing distances is a function of a length of the vehicle (V_L) **102**. Also, a third command can be configured to command the steering system **104** to be in a counter-clockwise position while the vehicle **102**, V_H is moving in a reverse direction for a third reversing distance, wherein a distance traveled during the first, second, and third reversing distances is a function of the determined distances, a longitudinal displacement of the vehicle **102**, V_H during the first, second, and third commands, and a lateral displacement of the vehicle **102**, V_H during the first, second, and third commands, as set forth in greater detail herein.

According to one embodiment, the parallel parking assistant system **100** can use the sensor **106** that is a short-range distance sensor. The sensor **106** can be positioned on a passenger side of the vehicle **102**, V_H, such that the parallel parking assistant system **100** is configured to parallel park the vehicle **102**, V_H with respect to the passenger side of the vehicle **102**, V_H as a function of one or more outputs of the sensor **106**. Typically, the sensor **106** can be located on the passenger side of the vehicle **102**, V_H in order to measure the offset distance X_{OFFSET} (FIG. **3**) between the vehicle **102**, V_H and an adjacent object (e.g., an adjacently parked vehicle V_F). According to one embodiment, the offset distance X_{OFFSET} can be a minimum distance between the vehicle **102**, V_H and the forward positioned object V_F, a maximum distance between the vehicle **102**, V_H and the rear positioned object V_F, or an average distance between the vehicle **102**, V_H and the forward positioned object V_F and the vehicle **102**, V_H and the rear positioned object Y_R. However, it should be appreciated by those skilled in the art that other suitable determined, measured, or calculated distances can be used to determine the offset distance X_{OFFSET}. The parallel parking assistant system **100** can then accomplish the parallel parking of the vehicle **102**, V_H by having three (3) turning sequences while the vehicle **102**, V_H is moving in a reverse direction, which can allow for both an autonomous, semi-autonomous, or manual mode, as described in greater detail herein.

For purposes of explanation and not limitation, the parallel parking assistant system **100** is illustrated and described herein with the sensor **106** being located on a passenger side of the vehicle **102**, V_H, such that the vehicle **102**, V_H is parallel parked with respect to the passenger side. However, it should be appreciated by those skilled in the art that an additional sensor or the sensor **106** can be located on a driver's side of the vehicle **102**, V_H, such that the parallel parking assistant system **100** can parallel park the vehicle **102**, V_H with respect to a driver's side of the vehicle **102**, V_H. By way of explanation and not limitation, the sensor **106**, **109** can be at least one of an ultrasonic sensor, a radar sensor, a lidar sensor, a camera, the like, or a combination thereof.

The controller **108** can be configured to be both, but only one at a time, in an autonomous mode, in a semi-autonomous mode, or in a manual mode according to one embodiment. Typically, the controller **108** can provide the commands to the steering system **104** when the controller **108** is in the autonomous mode. When the controller **108** is in the manual mode, the controller **108** can provide the commands to a user of the vehicle **102**, V_H, such that the user can control a steering system **104** of the vehicle **102**, V_H based upon the provided commands. In such a manual mode, the controller **108** can provide the commands by an audio enunciation, a visual output (e.g., one or more indicator lights, an output on a screen, such as, but not limited to, a navigation system screen), the like, or a combination thereof. The semi-autonomous mode can incorporate a portion of functions of the autonomous mode and a portion of functions of the manual mode. A configuration to switch between the autonomous mode, the semi-autonomous mode, and the manual mode can be configured by a manufacturer of the vehicle **102**, V_H, a manufacturer of the parallel parking assistant system **100** and/or other components of the vehicle **102**, V_H, a dealer or seller of the vehicle **102**, V_H, a user of the vehicle **102**, V_H, or a combination thereof.

The steering system **104** can include a steering wheel **110** operably connected to a front axle **112**, and the front axle **112** can be operably connected to one or more wheels **114**, according to one embodiment. Typically, when the steering system **104** is turned to a clockwise direction, the steering wheel **110** is activated or turned in a clockwise direction so that the one or more wheels **114** operably connected to the steering wheel **110** would direct the vehicle **102**, V_H in a clockwise direction when the vehicle **102**, V_H is traveling in a forward direction with respect to a normal operational position of the vehicle **102**, V_H. Similarly, when the steering system **104** is turned to a substantially straight or turned to a counter-clockwise direction, the steering wheel **110** is activated or turned in a substantially straight or counter-clockwise direction, so that the one or more wheels **114** operably connected to the steering wheel **110** would direct the vehicle **102**, V_H in a substantially straight or counter-clockwise direction when the vehicle **102**, V_H is traveling in a forward direction with respect to a normal operational position of the vehicle **102**, V_H, respectively.

According to one embodiment, the sensor **106** can be positioned on a rear portion of the passenger side of the vehicle **102**, V_H (FIG. **1**), such that the controller **108** can be configured to provide the first, second, and third commands as a function of a lateral displacement between the rear portion of the passenger side of the vehicle **102**, V_H and one or more objects adjacent thereto (e.g., a forward and rear parked vehicle V_F, V_R). The controller **108** can also be configured to provide a command prior to the first command, wherein the prior command can be configured to command the steering system **104** to be in a substantially straight position, while the vehicle **102**, V_H is moving in a forward direction from a rear positioned adjacent object towards a forward positioned adjacent object, such that the forward positioned adjacent object and rear positioned object define a parking space.

In such an embodiment, the second sensor **109** can be, but is not limited to, a wheel speed sensor configured to determine the distance between the forward positioned object (e.g., a forward parked vehicle V_F) and the rear positioned object (e.g., a rear parked vehicle V_R). Thus, the first sensor **106** can be used to measure an offset distance (X_{OFFSET}) to determine if a parking space exists, and the second sensor **109** can be used to measure a length of a parking space. However, it should be appreciated by those skilled in the art that the forward positioned object, the rear positioned object, or a combination thereof, can be objects other than vehicles, and that a description herein as to other parked vehicles is for purposes of explanation and not limitation. Additionally or alternatively, the second sensor **109** can be used to measure the first reversing distance, the second reversing distance, the third reversing distance, the like, or a combination thereof.

In regards to FIGS. **1**-**2**B, these figures illustrate exemplary dimensions that can be measured or can be known values within the parallel parking assistant system **100**. According to one embodiment, the sensor **106** is located on the passenger side of the vehicle **102**, V_H, wherein a distance Y_S is the distance between a most rear portion of the vehicle **102**, V_H and the sensor **106** (FIG. **1**). With respect to FIG. **2**A, the vehicle **102** (or host vehicle V_H) length V_L can be determined by the distance between an approximate center point of a rear axle **116** to approximately a front bumper **118**. Alternatively, in a flat-front vehicle **102**, V_H type (FIG. **2**B), the vehicle **102**, V_H length V_L can be from an approximate center point of the rear axle **116** to approximately a front corner of the vehicle **102**, V_H.

In regards to FIG. **3**, a width of the vehicle **102**, V_H is represented by X_{WIDTH}, and a displacement between the vehicle **102**, V_H and a front parked vehicle V_F is represented by X_{OFFSET}. Typically, the displacement value X_{OFFSET} is measured by the sensor **106**. A longitudinal value Y_{SPACE} of an available parking space, which is typically defined by the space between the front parked vehicle V_F and a rear parked vehicle V_R can be determined. The longitudinal value Y_{SPACE} can be measured by a second sensor **109**, such as, but not limited to, a wheel speed sensor. A total lateral displacement resulting from a completed parallel park maneuver can be represented by X_{TOTAL}, while the total longitudinal displacement resulting from a completed parallel park maneuver can be represented by Y_{TOTAL}. Also, a total distance traveled by the host vehicle **102**, V_H to complete a parallel park maneuver can be represented by L_{TOTAL}.

Typically, to conduct a parallel parking procedure, the displacement X_{OFFSET} between the host vehicle **102**, V_H and a front park vehicle V_F can be limited within the bounds of:

$$0<X_{MIN}<X_{OFFSET}<X_{MAX} \quad \text{Eq. 1}$$

Typically, variables X_{MAX} and X_{MIN} are selected based upon allowing satisfaction of geometric approximation of turning procedures. The variable X_{MIN} can be limited by the distance to an adjacent object (e.g., the front parked vehicle V_F), since the vehicle **102**, V_H cannot be located in the exact same position as any part of the adjacent objects (e.g., parked vehicle's V_F, V_R), and thus, the variable X_{MIN} has a value of greater than zero. According to one embodiment, the variable X_{OFFSET} has a value that is equal to or greater than approximately six inches (6 in), and the variable of X_{MAX} can have a value suitable to ensure the vehicle **102**, V_H is approximately one driving lane over from the adjacent objects (e.g., parked vehicles V_F, V_R). However, it should be appreciated by those skilled in the art that the variable X_{MAX} can have any value, but may be limited by other factors, such as, but not limited to, typical dimensions of roadways, a turning radius of the vehicle **102**, V_H, an error or tolerance of a travel path shape or distance, the like, or a combination hereof. Additionally or alternatively, the value of the displacement X_{OFFSET} can vary, such that the value of the displacement X_{OFFSET} can be, but is not limited to, a combination of values or an average of values.

A total lateral displacement X_{TOTAL} can result in an edge alignment of the vehicle **102**, V_H and a front parked vehicle V_F, which can be represented by:

$$X_{TOTAL}=X_{OFFSET}+X_{WIDTH} \quad \text{Eq. 2}$$

The total longitudinal displacement Y_{TOTAL} for a parallel parking operation can be determined to be able to fit into an allowable parking space as represented by the following equation:

$$Y_{TOTAL}<Y_{SPACE} \quad \text{Eq. 3}$$

With respect to FIG. **4**, in an embodiment that is utilizing a three (3) steering system **104** turning operation (e.g., two (2) opposing turning backward maneuvers connected by a substantially straight or linear backing maneuver), various displacement values can be determined. Typically, the first turning backing maneuver is where the steering system **104** is substantially locked in a clockwise direction, and the linear backing maneuver can be with the steering system **104** is substantially straight (e.g., $\theta_{STEERING}=0°$). Further, the second turning backing operation can be where the steering system **104** is substantially locked in a counter-clockwise direction. According to one embodiment, the steering system **104** is locked when the steering wheel **110** is turned a maximum position in either direction.

The first turning backing maneuver in combination with the substantially straight backing maneuver can be configured so that a front end of the vehicle **102**, V_H does not contact the front parked vehicle V_F when the vehicle **102**, V_H is conducting the second turning backing maneuver, according to one embodiment. Various longitudinal displacement values of the vehicle **102**, V_H during the three (3) steering system **104** turning operation that can be determined are a displacement resulting from a first turning backing maneuver Y_{T1}, a displacement resulting from the substantially straight backing maneuver Y_L, and a displacement resulting from a second turning backing maneuver Y_{T2}. A total longitudinal displacement Y_{TOTAL} can be calculated utilizing the following equation:

$$Y_{TOTAL}=Y_{T1}+Y_L+Y_{T2} \quad \text{Eq. 4}$$

Additionally, the vehicle **102**, V_H can have a lateral displacement when utilizing the three (3) steering system **104** turning operation. Various lateral displacement values that can be determined include a displacement resulting from first turning backing maneuver X_{T1}, a displacement resulting from a substantially straight backing maneuver X_L, and a displacement resulting from a second turning backing maneuver X_{T2}. A total lateral displacement X_{TOTAL} can be calculated utilizing the following equation:

$$X_{TOTAL}=X_{T1}+X_L+X_{T2} \quad \text{Eq. 5}$$

In regards to FIGS. **5** and **6**, exemplary geometry characteristics of a parallel parking maneuver are shown. Typically, a motion of one or more rear wheels **114** is approximated by a circle when substantially locking the steering system **104** while performing a backing maneuver (FIG. **6**). However, front wheels **114** of the vehicle **102**, V_H typically do not have the same turning radius as rear wheels **114**, and the rear axis **116** can point to a center of an imaginary circle, such that a frame of reference is a center point of the rear axle **116** (e.g., a motion traveled). Circle characteristics with respect to the rear axle **116** of the vehicle **102**, V_H can include a radius of an exemplary turning circle R, angle displacement by a turn θ, and a length of arc traveled by the angle displacement L. Typically, for a small angle displacement θ, the circle approximation is nearly correct. This condition can be ensured by satisfaction within geometric bounds of the parallel parking procedure. According to one embodiment, testing can be conducted with the vehicle **102**, V_H to obtain data and provide table look up values of "R" and "L" variables for various circumstances.

Longitudinal displacement geometric relationships (FIG. **5**) can be calculated by the following equations:

$$Y_{T1}=R_{T1}\sin(\theta_{T1}) \quad \text{Eq. 6}$$

$$Y_L=L_L\cos(\theta_{T1}) \quad \text{Eq. 7}$$

$$Y_{T2}=R_{T2}\sin(\theta_{T2}) \quad \text{Eq. 8}$$

Lateral displacement geometric relationships (FIG. **5**) can be calculated using the following equations:

$$X_{T1}=R_{T1}-R_{T1}\cos(\theta_{T1})=R_{T1}[1-\cos(\theta_{T1})] \quad \text{Eq. 9}$$

$$X_L=L_L\sin(\theta_{T1}) \quad \text{Eq. 10}$$

$$X_{T2}=R_{T2}-R_{T2}\cos(\theta_{T2})=R_{T2}[1-\cos(\theta_{T2})] \quad \text{Eq. 11}$$

The vehicle **102**, V_H motion displacement along a circular arc can have various characteristics. A distance traveled from a first turning backing maneuver L_{T1} can be calculated using the following equation:

$$L_{T1}=R_{T1}\theta_{T1}, \text{ (wherein } \theta_{T1} \text{ is specified in radians)}$$

A distance traveled from a substantially straight backing maneuver L_L can be determined. Also, a distance traveled from a second turning backing maneuver L_{T2} can be calculated by the following equation:

$$L_{T2}=R_{T2}\theta_{T2} \text{ (wherein } \theta_{T2} \text{ is specified in radians)} \quad \text{Eq. 13}$$

Thus, a total distance traveled can be represented by L_{TOTAL}, and calculated by the following equation:

$$L_{TOTAL}=L_{T1}+L_L+L_{T2} \quad \text{Eq. 14}$$

On-board vehicle motion sensors such as, but not limited to, the second sensor **109** (e.g., wheel speed sensors), can provide actual measurements of motions traveled parameters (e.g., L_{T1}, L_L, L_{T2}) and approximately translated to a rear axle coordinate frame, according to one embodiment. Measured parameters can include a measured distance traveled from a first turning backing maneuver L_{T1M}, a measured distance traveled from a substantially linear backing maneuver L_{LM}, and a measured distance traveled from a second turning back maneuver L_{T2M}.

According to one embodiment, opposing circular backing maneuver characteristics can be substantially identical. In such an embodiment, the host vehicle **102**, V_H can have backing dynamic motion parameter characteristics R, S, and θ that are substantially identical when the steering system **104** is substantially locked in either the clockwise or counter-clockwise position. When assuming the turning characteristics are substantially identical, then the various backing dynamic motion parameter characteristics can be calculated by the following equations:

$$\theta_T=\theta_{T1}=\theta_{T2} \quad \text{Eq. 15}$$

$$R_T=R_{T1}=R_{T2} \quad \text{Eq. 16}$$

$$L_T=L_{T1}=L_{T2} \quad \text{Eq. 17}$$

Substitutions of Equations 15 and 16 into Equations 4-11, and simplification thereof yields:

$$Y_{TOTAL}=2Y_T+Y_L=2R_T\sin(\theta_T)+L_L\cos(\theta_T) \quad \text{Eq. 18}$$

$$X_{TOTAL}=2X_T+X_L=2R_T[1-\cos(\theta_T)]+L_L\sin(\theta_T)$$

According to one embodiment, the longitudinal and lateral displacements of the vehicle **102**, V_H doing the first turning backing maneuver Y_{T1}, X_{T1}, and the substantially straight backing maneuver Y_L, X_L, are determined to ensure vehicle's **102**, V_H front bumper **118** does not contact the front parked vehicles V_F rear bumper when performing the second turning backing maneuver (FIG. **4**). In such an embodiment, a length L_V of the vehicle **102**, V_H can be substantially equal to the combined longitudinal components of the first backing maneuver Y_{T1} and the substantially straight backing maneuver Y_L, as represented by the following equation:

$$L_V=Y_{T1}+Y_L \quad \text{Eq. 20}$$

Substitution of Equations 6 and 7 with Equations 15 and 16 into Equation 20 yields:

$$L_V=R_T\sin(\theta_T)+L_L\cos(\theta_T) \quad \text{Eq. 21}$$

Solving Equation 21 for L_L is represented by the following equation:

$$L_L=\frac{L_V}{\cos(\theta_T)}-R_T\tan(\theta_T) \quad \text{Eq. 22}$$

Total linear displacement X_{TOTAL} to accomplish a parallel parking maneuver can be calculated by substituting Equations 2 and 22 into Equation 19, which yields the following equation:

$$X_{OFFSET}+X_{WIDTH}=2R_T[1-\cos(\theta_T)]+\left[\frac{L_V}{\cos(\theta_T)}-R_T\tan(\theta_T)\right]\sin(\theta_T) \quad \text{Eq. 23}$$

Further simplification of Equation 23 yields:

$$X_{OFFSET}+X_{WIDTH}=R_T[2-2\cos(\theta_T)-\sin(\theta_T)\tan(\theta_T)]+L_V\tan(\theta_T) \quad \text{Eq. 24}$$

Solving for a subtended angle displaced by a turn θ_T from Equation 24, wherein the parameters set (X_{OFFSET}, X_{WIDTH},

R_T, L_V) are typically known values, yield the following closed-form geometric equation:

$$\theta_T=f(X_{OFFSET},X_{WIDTH},R_T,L_V) \quad \text{Eq. 25}$$

Typically, θ_T of Equation 24 is solved using numerical analysis techniques. According to one embodiment, the values of X_{OFFSET}, X_{WIDTH}, R_T, and L_V can be known values because these values are determined using the first sensor **106** and/or the second sensor **109**, they are measureable parameters of the vehicle **102**, V_H, the like, or a combination thereof.

Total longitudinal displacement Y_{TOTAL} required for a parallel parking maneuver can be represented by substituting Equation 22 into Equation 18, which yields the following equation:

$$Y_{TOTAL}=2R_T\sin(\theta_T)+\left[\frac{L_V}{\cos(\theta_T)}-R_T\tan(\theta_T)\right]\cos(\theta_T) \quad \text{Eq. 26}$$

Further simplification of Equation 26 yields the following equation:

$$Y_{TOTAL}=R_T\sin(\theta_T)+L_V \quad \text{Eq. 27}$$

Knowing θ_T by utilizing Equation 25, then Equation 27 can yield the following closed-form geometric equation:

$$Y_{TOTAL}=R_T\sin(f(X_{OFFSET},X_{WIDTH},R_T,L_V))+L_V \quad \text{Eq. 28}$$

Typically, the parameters set X_{OFFSET}, X_{WIDTH}, R_T, and L_V are known values, wherein, the values of X_{OFFSET}, X_{WIDTH}, R_T, and L_V can be known values because these values are determined using the first sensor **106** and/or the second sensor **109**, they are measureable parameters of the vehicle **102**, V_H, the like, or a combination thereof. According to one embodiment, the potential parking space is sufficiently long enough to accommodate the parallel parking maneuver if Equation 28 satisfies Equation 3.

With respect to FIG. **7**, known vehicle system parameters can include X_{WIDTH}, R_T, L_V, Y_S, X_{MAX}, and X_{MIN}, according to one embodiment. When a user of the vehicle **102**, V_H desires to parallel park, the user can stop the vehicle **102**, V_H at Position **1** and enable the parallel parking assistant system **100**. The vehicle **102**, V_H can then move forward slowly (autonomous or semi-autonomously) past the rear adjacent object (e.g., the rear parked vehicle V_R), and potential parking space, until the sensor **106** detects the forward adjacent object (e.g., the forward parked vehicle V_F). The vehicle **102**, V_H motion will stop at Position **2** when the vehicle **102**, V_H rear bumper is aligned with the forward parked vehicle V_F rear bumper. The length of the parking space Y_{SPACE} can be measured from a vehicle **102**, V_H motion sensor (e.g., a wheel speed sensor). An offset distance X_{OFFSET} can be measured from the sensor **106**, and longitudinal distance Y→TOTAL can be calculated from Equation 28.

The parallel parking assistant system **100** can inform a driver of the vehicle **102**, V_H whether the potential parking space is suitable for parallel parking operation when the conditions Equations 1 and 2 are met. If the parallel parking space is suitable, the user of the vehicle **102**, V_H can engage the parallel parking assisting system **100** to allow the vehicle **102**, V_H to move backwards slowly (autonomously or semi-autonomously) to perform the following three (3) backing maneuvers sequences.

The first backing steering maneuver can include the steering system **104** being substantially in clockwise locking position. The vehicle **102**, V_H moves backwards until the following transitional conditions are met:

$$L_{T1M}=L_{T1} \quad \text{Eq. 29}$$

Using Equation 12 with Equations 15 and 16 yields:

$$L_{T1M}=R_T\theta_T \text{ (wherein } \theta_T \text{ is translated into radians)} \quad \text{Eq. 30}$$

Using Equation 25, Equation 30 then becomes:

$$L_{T1M}=R_Tf(X_{OFFSET},X_{WIDTH},R_T,L_V) \quad \text{Eq. 31}$$

The substantially linear or straight backing maneuver can be when the steering system **104** is substantially straight (e.g., $\theta_{STEERING}=0°$), wherein the vehicle **102**, V_H moves backward until the following transitional conditions are met:

$$L_{LM}=L_L \quad \text{Eq. 32}$$

Using Equation 22 with Equation 32 yields:

$$L_{LM}=\frac{L_V}{\cos(\theta_T)}-R_T\tan(\theta_T) \quad \text{Eq. 33}$$

Using Equation 25, then Equation 33 becomes:

$$L_{LM}=\frac{L_V}{\cos(f(X_{OFFSET},X_{WIDTH},R_T,L_V))}-R_T\tan(f(X_{OFFSET},X_{WIDTH},R_T,L_V)) \quad \text{Eq. 34}$$

The second backing steering maneuver can be accomplished when the steering system **104** is substantially locked in a counter-clockwise position, and the vehicle **102**, V_H moves backwards until the following stopping condition is met:

$$L_{T2M}=L_{T2} \quad \text{Eq. 35}$$

Using Equation 12 with Equations 15 and 16 yields:

$$L_{T2M}=R_T\theta_T \text{ (wherein } \theta_T \text{ is translated into radians)} \quad \text{Eq. 36}$$

Using Equation 25, then Equation 26 becomes:

$$L_{T2M}=R_Tf(X_{OFFSET},X_{WIDTH},R_T,L_V) \quad \text{Eq. 37}$$

The vehicle **102**, V_H can then be positioned between the two parked vehicles V_F, V_R, or adjacent objects that define the parking space.

With respect to FIGS. **1-8**, a method of parallel parking the vehicle **102**, V_H that includes the steering system **104** is generally shown in FIG. **8** at reference identifier **200**. The method **200** starts at step **202**, and can proceed to step **204**, wherein a longitudinal space between a front adjacent object (e.g., a forward positioned object, such as, but not limited to, a front parked vehicle V_F) and a rear adjacent object (e.g., a rear positioned object, such as, but not limited to, a rear parked vehicle V_R) is measured, according to one embodiment. The method **200** then proceeds to step **206**, wherein a longitudinal parking distance is calculated.

At decision step **208**, it is determined if the parking space is adequately long enough (e.g., Y_{TOTAL} is less than Y_{SPACE}). If it is determined at decision step **208** that the parking space is not adequately long enough, then the method **200** proceeds to step **216**, wherein the method **200** ends. However, if it is determined at decision step **208** that the parking space is adequately long enough, the method **200** proceeds to step **210**. At step **210**, the first turning operation is implemented. Typically, the first turning operation includes turning the steering system **104** in a counter-clockwise direction, while the vehicle **102**, V_H travels a first reversing distance. At step **212** a substantially straight operation is implemented, and at step **214**, a second turning operation is implemented. Typically, the second turning operation includes turning the steering system **104** in a clockwise direction, while the vehicle **102**, V_H travels a third reversing distance. The method **200** then ends at step **216**.

Advantageously, the parallel parking assistant system **100** and method **200** can be utilized to park a vehicle **102**, V_H within a parking space defined by two objects, such as two parked vehicles V_F, V_R, wherein the parallel parking assistant system **100** can be an autonomous mode, a semi-autonomous mode, or a manual mode. The parallel parking assistant system **100** provides assistance to a driver of the vehicle **102**, V_H to parallel park the vehicle **102**, V_H, while requiring minimal hardware by utilizing a single sensor **106**, which can reduce a cost of manufacturing. It should be appreciated by those skilled in the art that the parallel parking assistant system **100** and method **200** can have additional or alternative advantages. It should further be appreciated by those skilled in the art that the above-described components of the parallel parking assistant system **100** and steps of the method **200** can be combined in additional or alternative ways.

Modifications of the invention will occur to those skilled in the art and to those who make or use the invention. Therefore, it is understood that the embodiments shown in the drawings and described above are merely for illustrative purposes and not intended to limit the scope of the invention, which is defined by the following claims as interpreted according to the principles of patent law, including the doctrine of equivalents.

The invention claimed is:

1. A parallel parking assistant system integrated with a vehicle that comprises a steering system, a brake system, and a throttle system, said parking assistant system comprising:

a first sensor configured to determine a first distance to an object adjacent to a side of the vehicle; and

a second sensor configured to determine a second distance between a forward positioned object and a rear positioned object that define a parking space;

a controller in communication with said first and second sensors, wherein said controller is configured to provide commands to control the steering system of the vehicle as a function of said determined first and second distances, said provided commands comprise:

a first command configured to command the steering system to be in a clockwise position while the vehicle is moving in a reverse direction for a first reversing distance;

a second command configured to command the steering system to be in a substantially straight position while the vehicle is moving in a reverse direction for a second reversing distance, wherein a distance traveled during said first and second reversing distances is a function of a length of the vehicle; and

a third command configured to command the steering system to be in a counter-clockwise position while the vehicle is moving in a reverse direction for a third reversing distance, wherein a distance traveled during said first, second, and third reversing distances is a function of said determined first and second distances, a longitudinal displacement of the vehicle during said first, second, and third commands, and a lateral displacement of the vehicle during said first, second, and third commands.

2. The parallel parking assistant system of claim **1**, wherein said longitudinal and lateral displacement of the vehicle during said first, second, and third commands is a function of a length of a parking space (Y_{SPACE}), an offset distance between the vehicle and a forward positioned object (X_{OFFSET}), and a width of the vehicle (X_{WIDTH}).

3. The parallel parking assistant system of claim **1**, wherein said sensor is at least one of ultrasonic, radar, lidar, and a camera.

4. The parallel parking assistant system of claim **1**, wherein said controller is configured to be all, but only one at a time, in a manual mode, an autonomous mode, and a semi-autonomous mode.

5. The parallel parking assistant system of claim **4**, wherein said controller provides said commands to the steering system, the brake system, and the throttle system, when said controller is in said autonomous mode, and provides said commands to a user of the vehicle, who then controls the steering system, the brake system, and the throttle system, based upon said provided commands when said controller is in said manual mode.

6. The parallel parking assistant system of claim **1**, wherein said first sensor is positioned on a rear portion of a passenger side of the vehicle, such that said controller is configured to provide said first command as a function of a lateral displacement between said rear portion of said passenger side of the vehicle and said object adjacent thereto.

7. The parallel parking assistant system of claim **1**, wherein said controller is further configured to provide a command prior to said first command that is configured to command the steering system to be in a substantially straight position while the vehicle is moving in a forward direction from rear positioned adjacent object towards a forward positioned adjacent object, such that said forward positioned adjacent object and a rear positioned adjacent object define a parking space and a longitudinal distance between said forward positioned adjacent object and said rear positioned adjacent object is determined by said second sensor.

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